EVALUATION OF CASCADED HUMIDIFIED ADVANCED TURBINE (CHAT) CYCLES FOR NATURAL GAS AND SYNGAS

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CHAT Cycle Features

- Lower product cost -- $/kW
- Shorter, lower cost development path
- Greater flexibility than CC in terms of start-up and load following
- CHAT design point efficiency equal to CC with better part load performance
- Low NOx emissions without DLN combustors

Why the CHAT Cycle is Attractive for the DOE Program

- The CHAT concept meets DOE performance and economic targets
- Further development concentrates on validation of the sophisticated thermal cycle rather than on more expensive development of new alloys, cooling techniques, etc.
- The CHAT concept is generic and can be applied to various CT

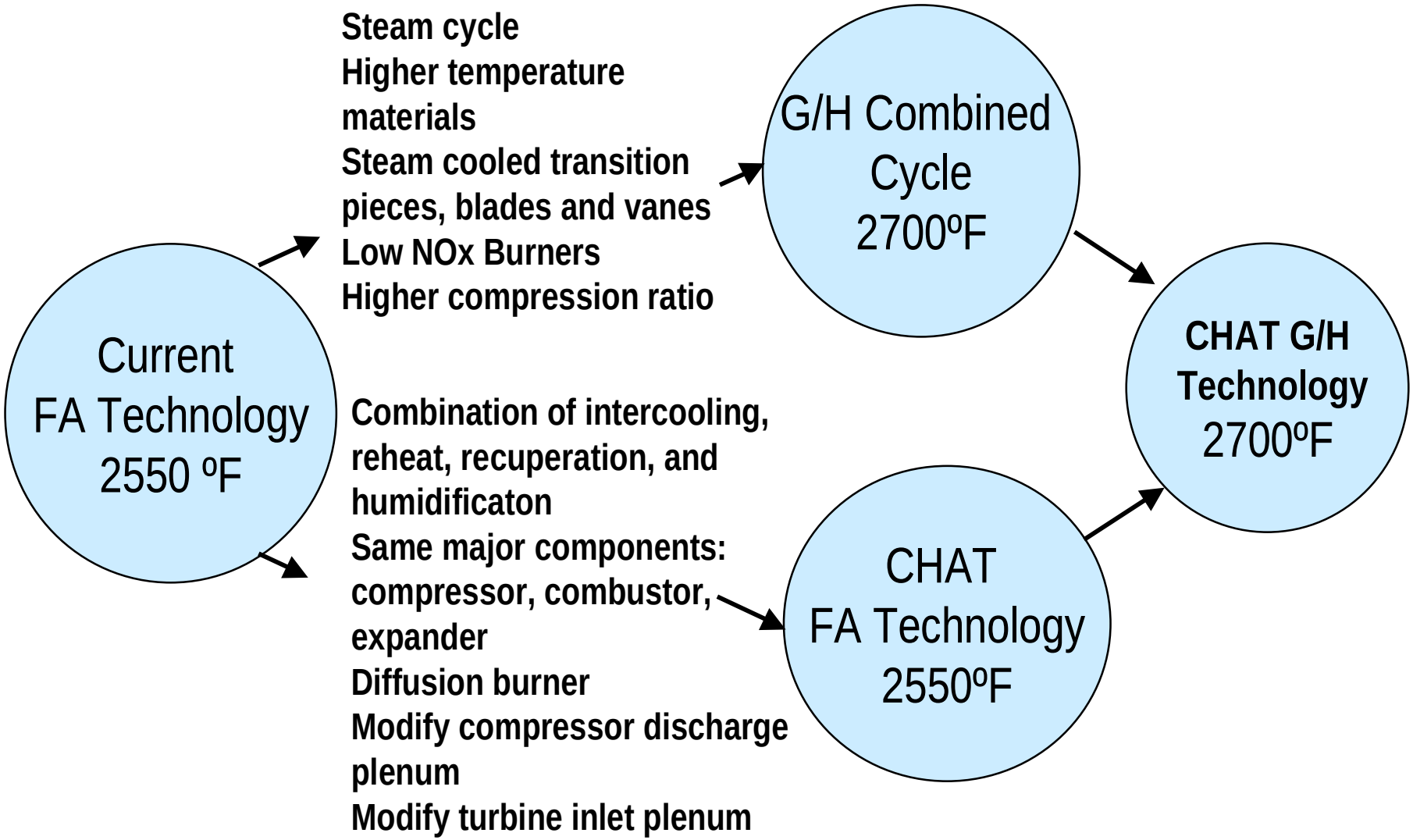
Obstacles to Further Development

- The CHAT concept pursues performance improvement via development of a sophisticated thermal cycle
- The CHAT cycle is different in that it involves intercooling, reheat, recuperation, and humidification
- This approach competes with the traditional route of increasing turbine inlet temperature
- No major vendor has committed to development of this product, which competes with their current offerings

Subjects of this Presentation

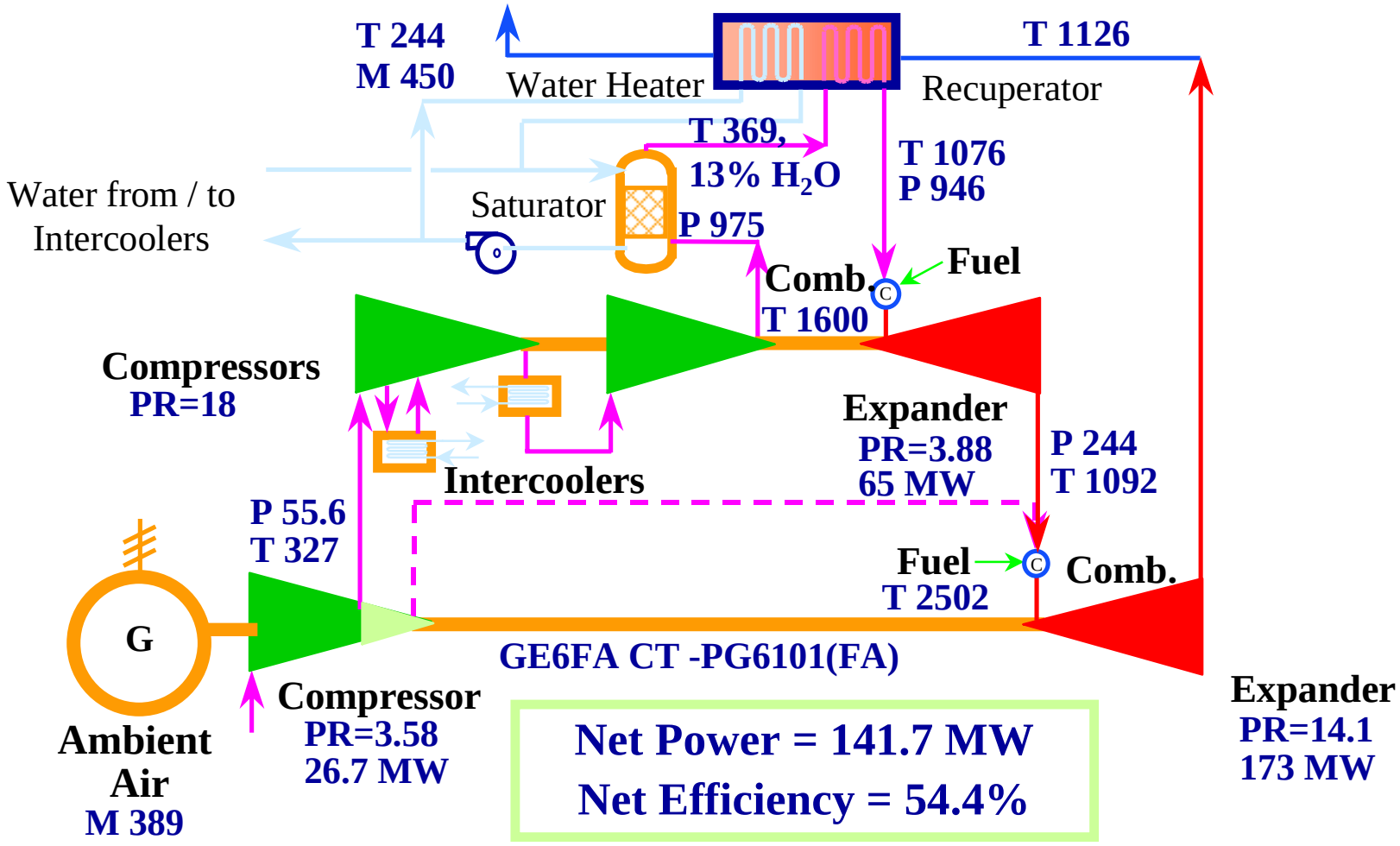
- **Conceptual designs for three natural gas fired CHAT plants ranging from 30 to 150 MWe in size**
- **Applicability of CHAT to integration with coal gasification and the potential for significant investment reductions**

Alternate Paths to Higher Efficiency on Natural Gas



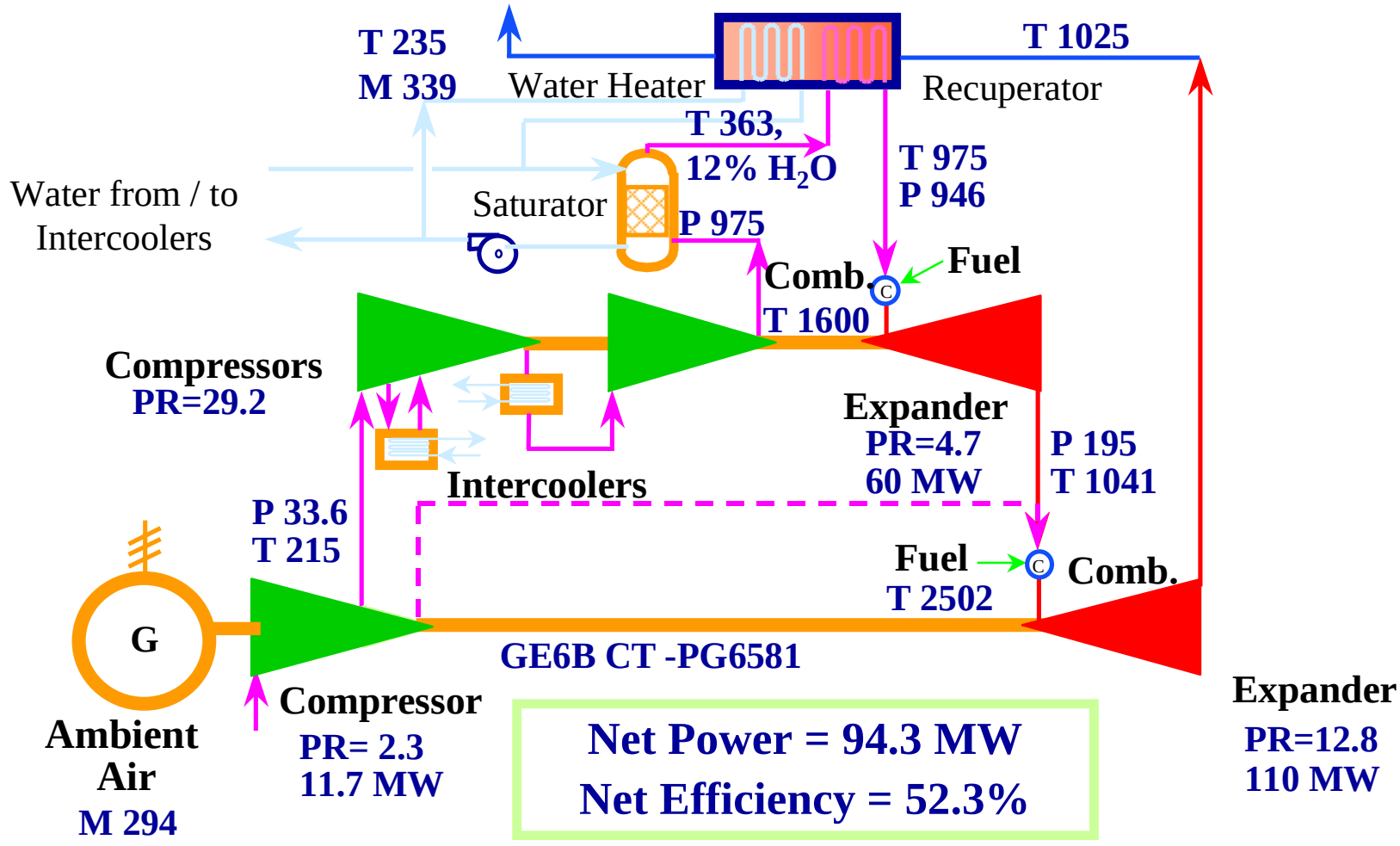
CHAT Cycle Diagram

GE 6FA CT



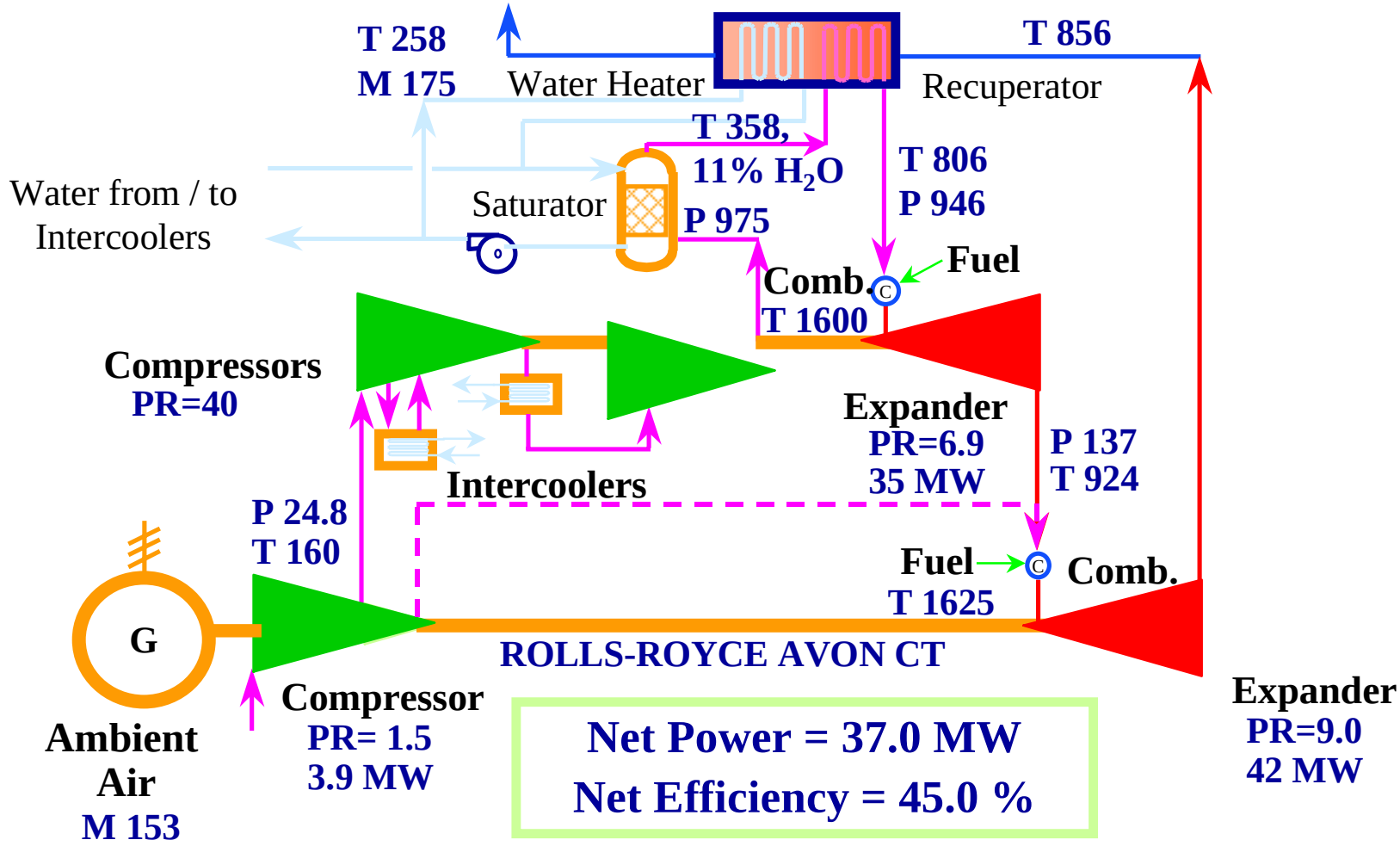
CHAT Cycle Diagram

GE 6B CT



CHAT Cycle Diagram

Rolls-Royce Avon CT



CT, CC, and CHAT Performance Comparison

Concept	Simple Cycle	Combined Cycle	CHAT
Based on GE PG6101 (FA) CT			
Net Power, MW	70.1	107.4	141.7
Net Heat Rate, Btu/kWh	9,980	6,440	6,269
Net Efficiency, %	34.2	53.0	54.4
Based on GE PG6581 (B) CT			
Net Power, MW	40.7	64.3	94.3
Net Heat Rate, Btu/kWh	10,750	6,970	6,524
Net Efficiency, %	31.7	49.0	52.3
Based on RR Avon CT			
Net Power, MW	13.9	N/A	37.0
Net Heat Rate, Btu/kWh	12,097		7,575
Net Efficiency, %	28.2		45.0

Comparison of GE 6FA CHAT Cycle with Simple and Combined Cycle

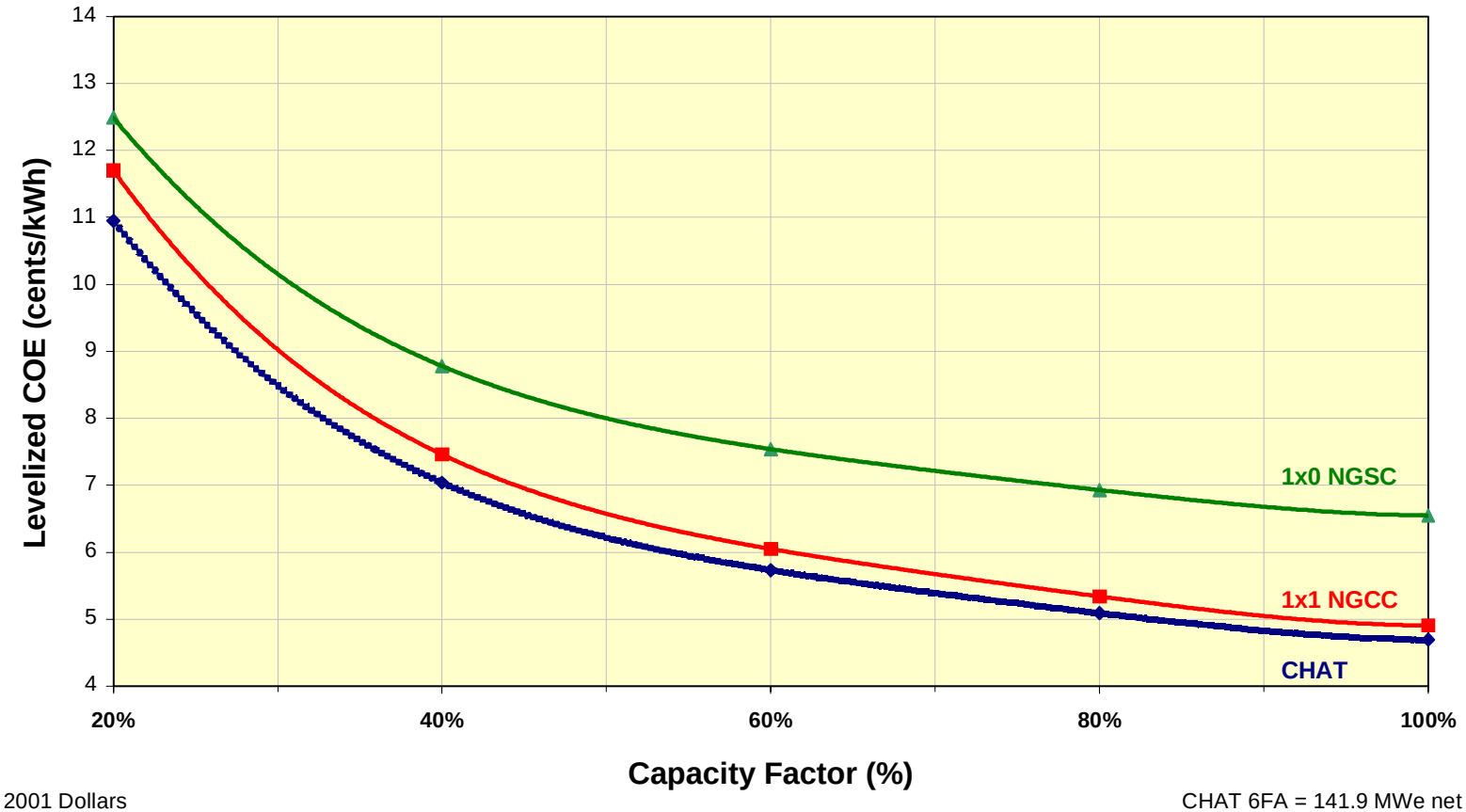
Performance, Capital Cost Comparison Table

Design Case	MWe	Capital Cost, $ x 10^6	Capital Cost, $/kWe	Efficiency, % LHV
GE 6FA CHAT	141.7	92.8	663	54.4
GE 6FA Comb. Cycle, 1x1	107.4	76.0	708	53.2
GE 6FA Simple Cycle	70.1	42.0	490	34.2

Note: Capital costs are presented on a Total Plant Cost basis.

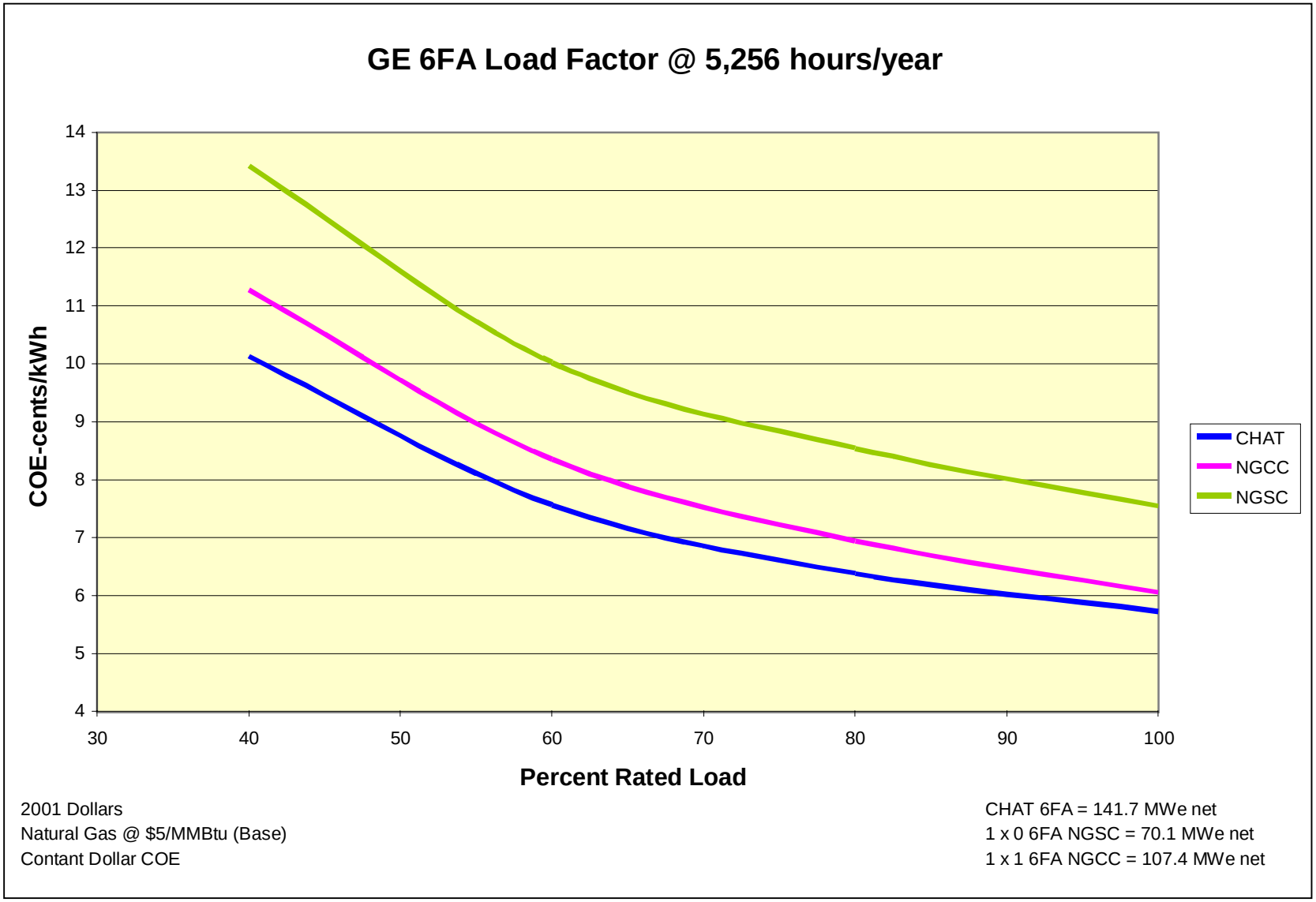
The following slides show total cost of electricity over a range of fuel costs, capital costs, and load factors for the GE 6FA based systems.

CHAT Economic Sensitivity (Capacity Factor) @ 59°F
Case: GE 6FA

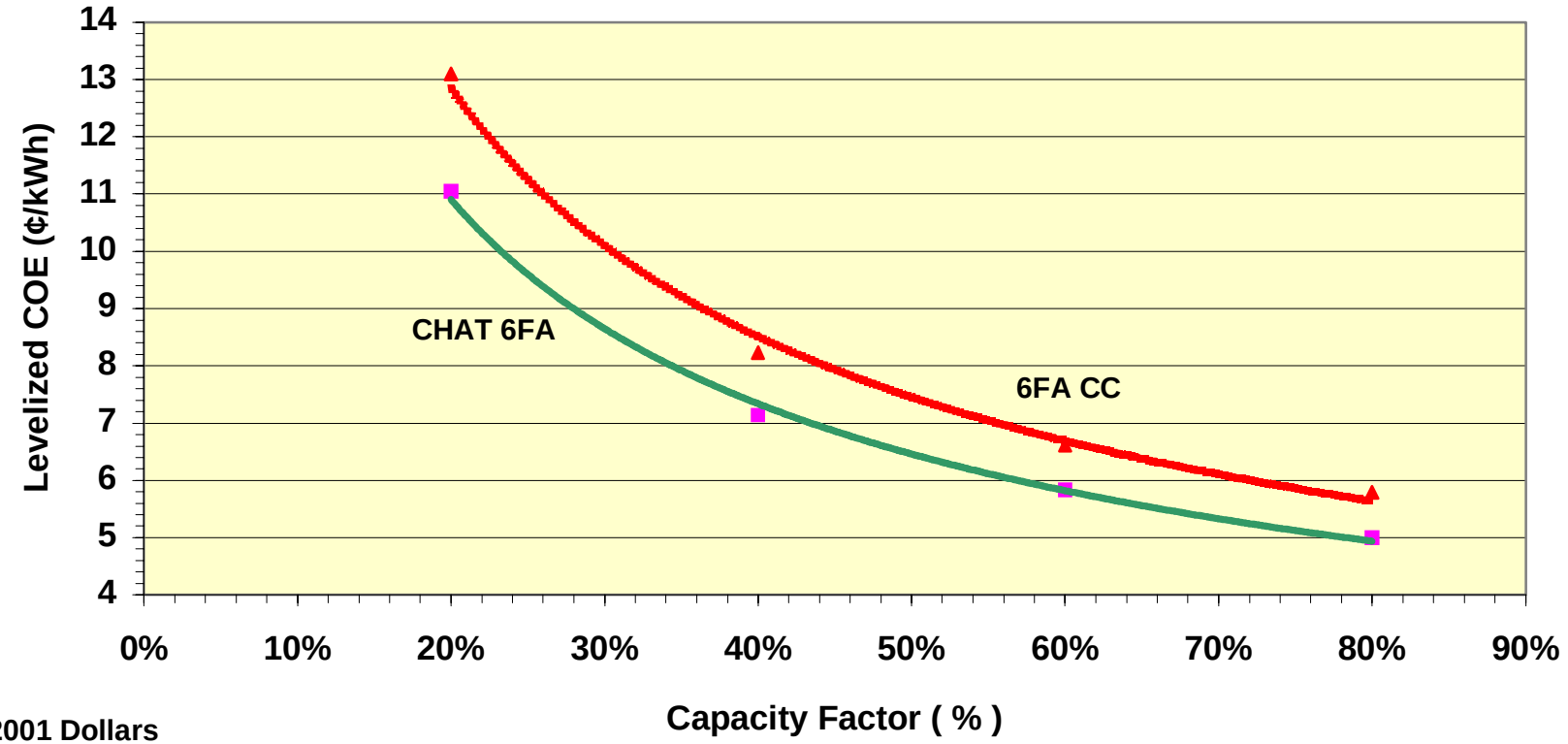


2001 Dollars
Natural Gas @ $5/MMBtu (Base)
Contant Dollar COE

CHAT 6FA = 141.9 MWe net
1 x 0 6FA NGSC = 69.0 MWe net
1 x 1 6FA NGCC = X MWe net


GE 6FA Load Factor @ 5,256 hours/year
COE-cents/kWh
14
13
12
11
10
9
8
7
6
5
4
30
40
50
60
70
80
90
100
Percent Rated Load
CHAT
NGCC
NGSC
2001 Dollars
Natural Gas @ $5/MMBtu (Base)
Contant Dollar COE
CHAT 6FA = 141.7 MWe net
1 x 0 6FA NGSC = 70.1 MWe net
1 x 1 6FA NGCC = 107.4 MWe net

CHAT Economic Sensitivity (Capacity Factor) @ 95°F
Case: CHAT 6FA vs. 6FA CC

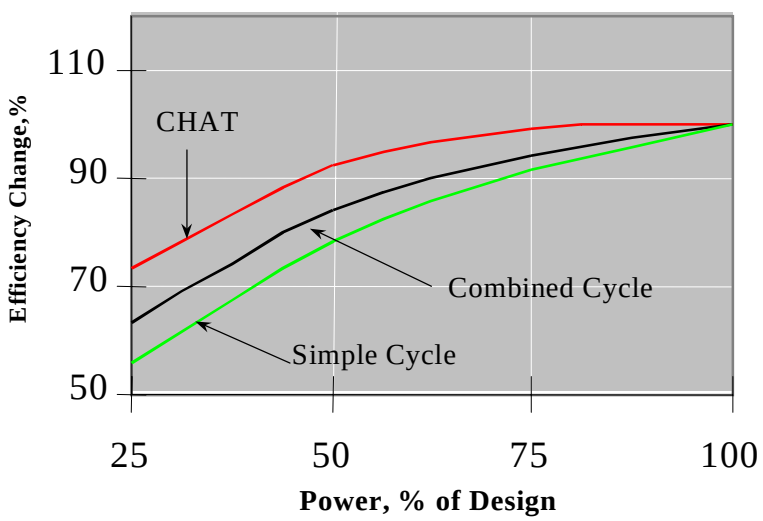


2001 Dollars
Natural Gas @ $5/MM Btu (Base)
Constant Dollar COE

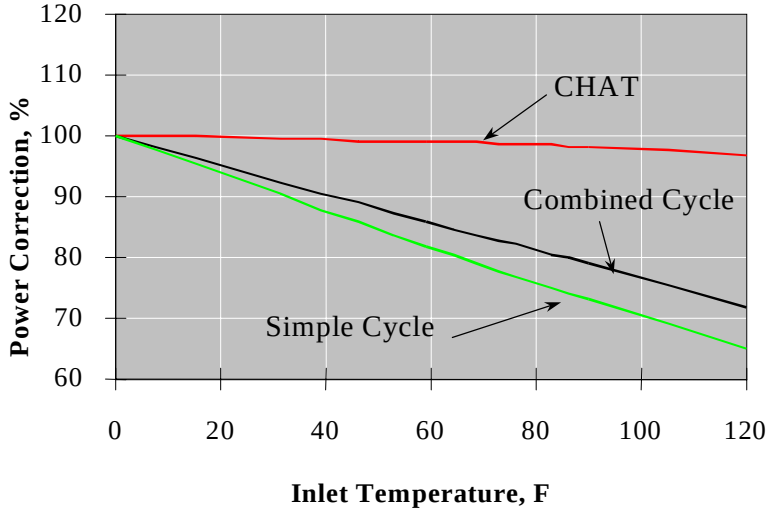
Part-Load & Ambient Temperature Effects

CHAT Cycle vs. Simple & Combined Cycles

Part-Load Efficiencies



Temperature Correction Curves

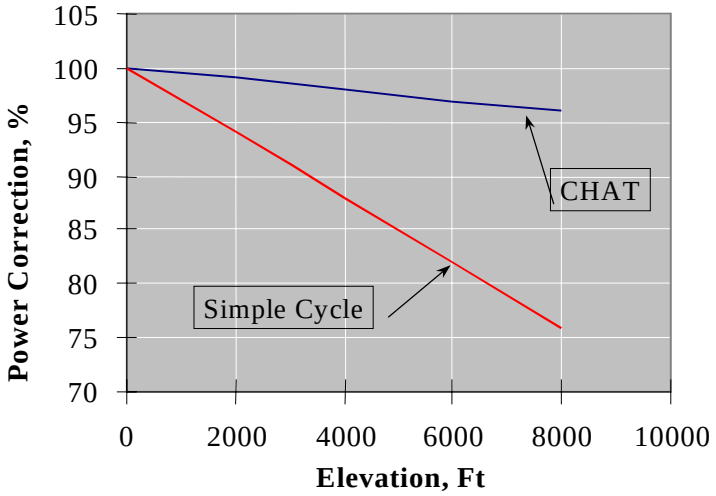


The CHAT cycle maintains high part-load efficiency, and high power output at high ambient temperatures by using humidification to compensate for cycle and machine behavior caused by fixed geometry.

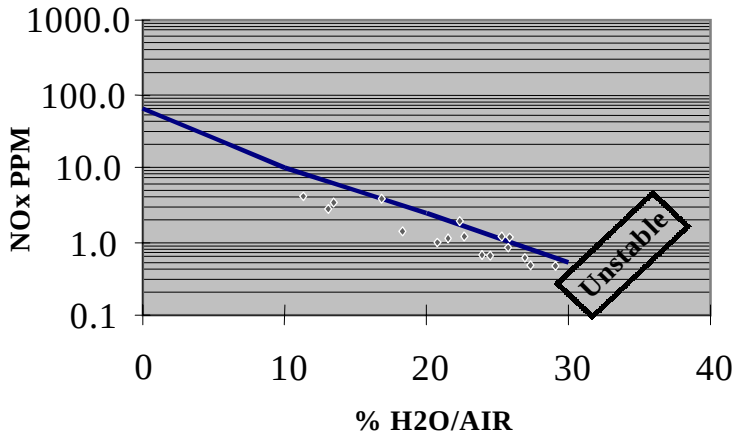
Altitude Effects, NOx Emissions

CHAT Cycle vs. Simple & Combined Cycles

Elevation Correction Curves



Emission Test Results

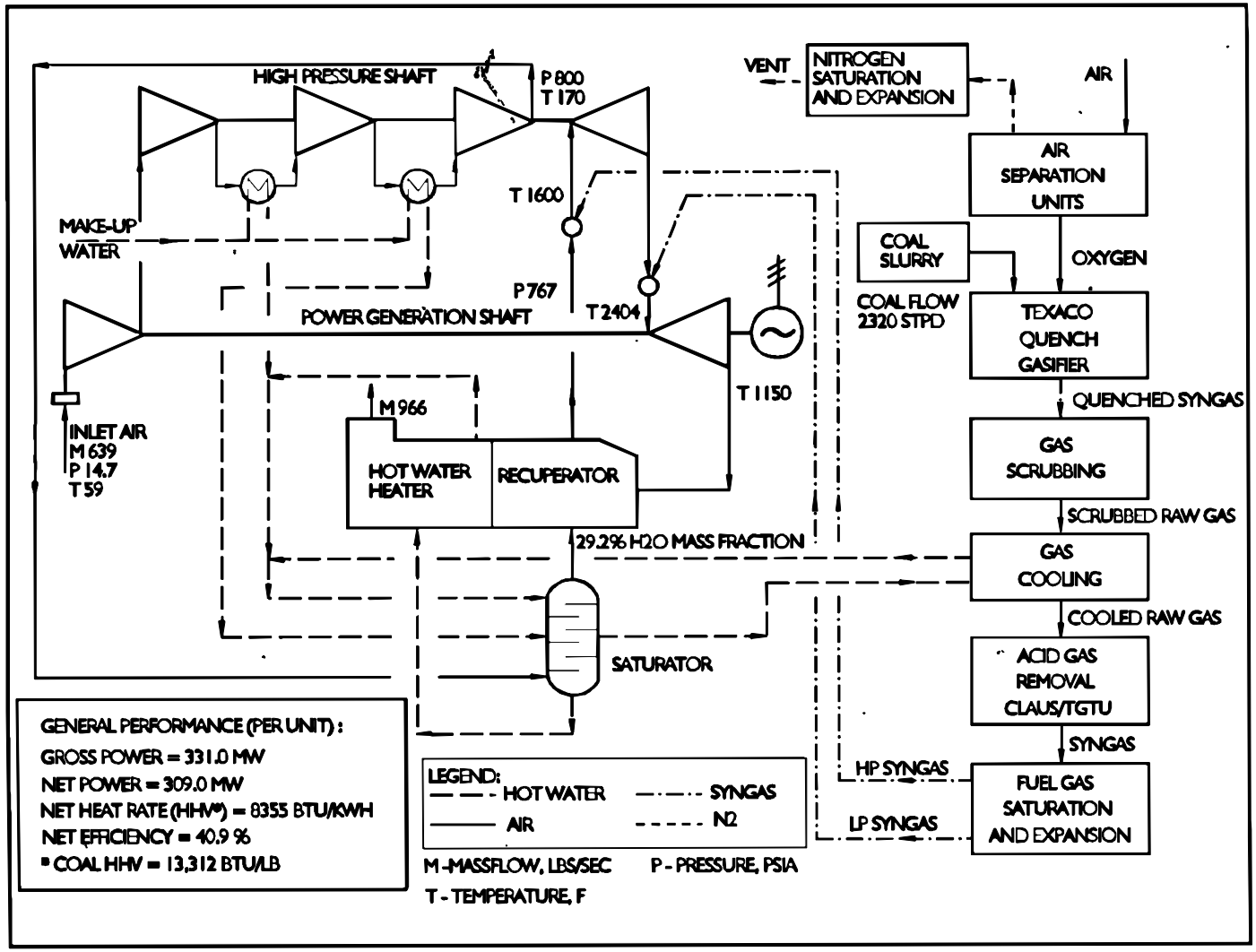


The CHAT cycle permits the amount of humidification to be varied to compensate for increased altitude, up to the combustion stability limit. NOx is reduced to single digit levels over the normal operating range.

Potential Advantages of Integrating Coal Gasification with the CHAT Cycle

- The cycle allows useful heat to be recovered as hot water that is evaporated in part into the gas entering the gas turbine rather than as steam entering the steam turbine
- This allows expensive high temperature heat exchange equipment to be replaced by a quench chamber

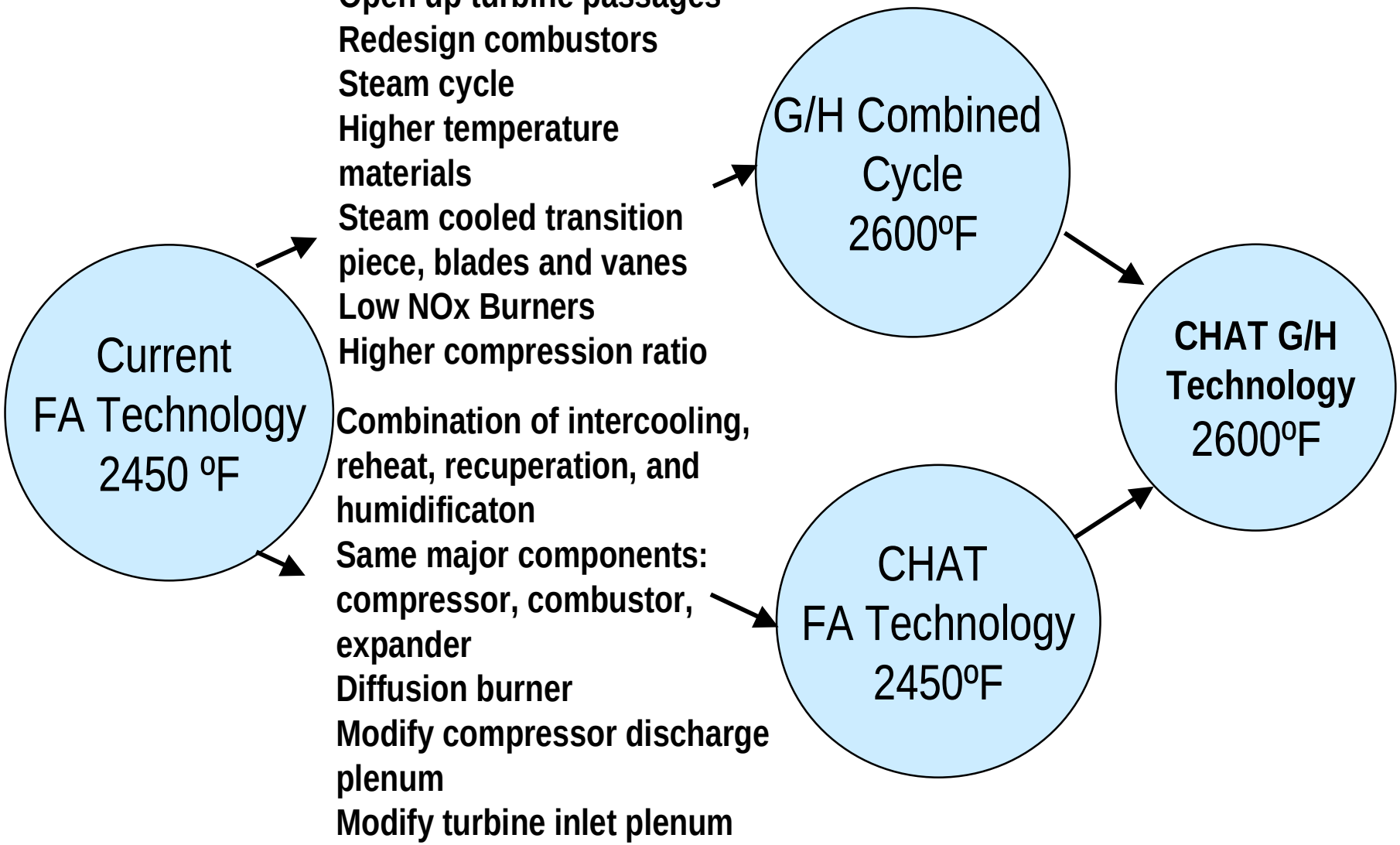
IGCHAT With Texaco Quench Gasifier



Comparison of IGCC with IGCHAT with Model F Gas Turbine Technology and Texaco High Efficiency Quench Gasifier (1994 Study)

Technology	IGCC	IGCHAT
Net power, MW	527.4	618.1
Net heat rate, Btu/kWh	8775	8355
Relative Investment		Minus 13.2% -- about $150/kW

Alternate Paths to Higher Efficiency on Syngas



CHAT Technology Growth Potential

- Use of advanced materials, cooling techniques, TBC, etc. in lieu of current CT technology used in this study
- Increase the HP expander inlet temperature from current 1600°F to 2000°F
- Humidification should reduce NOx emissions to single digit levels without DLN combustors
- CHAT technology is adaptable to various sizes, alternative fuels, and flexible operations

CHAT Cycle Evaluation – Conclusions

- **The CHAT cycle demonstrates a combination of the best characteristics of CT and CC plants:**
  - **Startup characteristics, operating flexibility, and load following are similar to or better than CT**
  - **Efficiency and part-load characteristics are better than CC plants based on the same CT**
- **The performance characteristics of each of the three CHAT plants (35, 95, and 145 MW) are significantly better than for the base CT:**
  - **Power is approximately double that of the base CT**
  - **Heat rate improved by approximately 35% relative to base CT**
  - **Better part-load efficiency, constant power over a wide range of temperatures, lower NOx**

CHAT Cycle Evaluation – Conclusions

- Cost estimates show that CHAT capital costs for all three sizes are between those of CT and CC for the same core engine
- CHAT capital costs can be lower than data used in study; major suppliers' (Dresser-Rand and Struthers Wells) components were not optimized
- CHAT cycle shows improved life cycle costs relative to combined cycle based on same core engine; can get even better with optimized components
- Results do not account for other CHAT cycle advantages, which would improve the comparison in real applications -- better hot day and part-load performance, better altitude performance, etc.

IGCHAT Conclusions

- **IGCHAT plants have the potential for significant investment savings and performance improvements for coal gasification based power plants**
- **“F” technology, which is commercially proven on syngas, can be utilized rather than higher temperature G/H technology which remains to be commercially proven (acceptable RAM) on natural gas**
- **Development path appears to less complex than future qualification of 400-500 MW single train combined cycle units for operation on syngas**